UNITED STATES PATENT APPLICATION

FOR

FAST SILICON PHOTODIODES

WITH HIGH BACK SURFACE REFLECTANCE IN A WAVELENGTH RANGE

CLOSE TO THE BANDGAP

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BACKGROUND OF THE INVENTION

5   1.   Field of the Invention

The present invention relates to semiconductor photodiodes, in particular to silicon photodiodes with highly reflective back surfaces as well as to methods of fabricating such structures.

10   2.   Prior Art

The performance of silicon photodiodes within the spectral range close to the bandgap (~ 1124 nm at 23 °C) depends on the quality of the back surface, as the light penetration depth at these wavelengths is large enough to

15   span the entire thickness of the die. The light reflectance from the back surface of the die should be maximized to improve the responsivity and quantum efficiency of the photodiode.

As shown in Figure 1, prior art silicon photodiode

20   structures use a sputtered metal layer or plating 1 (usually Au or Al) on the wafer back side over an n+ or p+ layer 2, followed by sintering at ~ 400 °C to provide a reliable back

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side electrical contact. Figure 1 also schematically shows the photodiode crystal bulk 3 and front side active area diffusion 4. As is well known, such structures are characterized by poor back surface reflectance, which becomes

5 important for the wavelength range of $\lambda \geq 950$ nm, since at these wavelengths the absorption length is comparable to the die thickness. Note that the thickness of a conventional silicon photodiode die is within the range 200 to 500 µm. Such thicknesses are usually required to absorb as much

10 incident near infrared light as possible, thereby maximizing the photodiode responsivity at $\lambda \geq 950$ nm.

To increase the quantum efficiency of silicon photodiodes in the near infrared spectral range, the back surface reflectance should be improved, and corresponding

15 methods using isolation layers are well known from solar cell physics and technology. However, these methods are not readily used in silicon photodiode design. In addition, a dielectric isolation layer 5 with the thickness h between the back side metal and silicon may deteriorate significantly

20 electrical properties of the back side contact, thereby forcing additional measures to improve the photodiodes' parameters such as responsivity, frequency bandwidth, rise time, etc. See Figure 2.

BRIEF DESCRIPTION OF THE DRAWINGS

The main ideas of the invention are demonstrated by the accompanying drawings.

Figure 1 is a simplified schematic cross section of a
5   typical, conventional structure for a front illuminated photodiode with a metal layer sputtered or plated on the die back side.

Figure 2 is a simplified schematic cross section of a front illuminated photodiode with the dielectric isolation
10   layer on the back side.

Figure 3 is a simplified schematic cross section of a photodiode structure having a back side mirror in accordance with the present invention.

Figure 4 shows schematically one arrangement of
15   electrical contacts on the die back side.

Figure 5 is a schematic cross section of a completed photodiode in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As previously discussed, improving the back surface reflectance of photodiodes often causes deterioration of the photodiode performance with respect to such properties as

5   frequency bandwidth and rise time. The present invention uses designs having an additional photomask on the wafer back side. This design corrects the above shortcomings, and provides for superior responsivity and temporal characteristics of silicon photodiodes within the spectral

10   range close to the bandgap.

Now referring to Figure 3, a simplified cross section of a local region illustrating the back side detail of a photodiode in accordance with the present invention may be seen. The structure may be fabricated using either *n*-type or

15   *p*-type bulk silicon substrate 3. For brevity, the region 4 of opposite conductivity type on the top surface of the substrate, the anode in the case of *p*-on-*n* structure or the cathode in the case of *n*-on-*p* structure will be referred to as "the first electrode", and the cathode in the case of *p*-

20   on-*n* structure and the anode in the case of *n*-on-*p* structure, will be referred to as "the second electrode".

The structure is obtained using an additional photomask/etch process on the back side of the photodiodes, resulting in the so-called "back dielectric mirror" with a

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periodic contact structure between metal layer 1 and n+ or p+ layer 2 (a layer of the same conductivity type as the substrate 3, though of a higher conductivity than the substrate), like that shown in Figure 3. The thickness h of

5 the dielectric layer (which, by way of example, may be an oxide or nitride layer) should preferably be approximately 1000 Å. In the exemplary structure of Figure 3, the extended regions of high reflectance of the back surface are separated from each other by the narrow strips of back side contact

10 metal 1, which serves as the second electrode. The width b of the contact opening strip should be $\geq$ 5 μm to provide a secure back side contact. The quality of the back side contact is important to get efficient and rapid collection of the non-equilibrium carriers. At the same time, the width of

15 the contact opening should be kept as narrow as possible because the back side reflection from the contact area is considerably lower than the reflectance from the dielectric mirror. The ratio a/b —see Figure 3 – should be chosen taking into account requirements on the responsivity

20 uniformity across the photodiode active area. For example, if the responsivity should be uniform with an accuracy of 5% when scanning the active area with the 1 mm diameter beam, then the total area S_{cont} of metal contacts enclosed inside the 1 mm diameter circle in any place across the back surface

of the die should not exceed the value (see Figure 4 as an example):

$$S_{cont} = \frac{\pi D^2}{4} \cdot 5\% = \frac{\pi D^2}{4} \cdot 0,05 \approx 0.039 \, \text{sq. mm} \, ,$$ (1)

in which D is the beam diameter (D = 1 mm in the case of our example). The total area S_0 of the 5-μm width (b = 5 μm) metal contacts enclosed within the circle D = 1 mm is:

$$S_0 \approx 2 \cdot D \cdot b = 2 \cdot 1 \cdot 0.005 = 0.01 \, \text{sq. mm}$$ (2)

From equations 1 and 2, it is clear that $S_0 < S_{cont}$; therefore, 5-μm width contact runs on the die back side satisfy the optimization requirements of securing a good electrical contact and high total reflectance of the back surface of the die.

If for the given structure the requirement $S_0 \leq S_{cont}$ does not hold, then the values of a and b (see Figures 3 and 4) preferably should be changed to keep the ratio a/b within optimal limits.

An exemplary method of fabricating a structure that satisfies the requirements of a high back surface optical reflectance and excellent electrical performance of the photodiode die comprises:

a)   A part of the front surface and back surface
     processing may be standard and is not the object of
     this invention. It may include, but may not be
     limited to:

5   - Guard ring/channel stopper deposition, drive, and
            oxidation – if required (not shown);

         - Back side contact doping – second electrode –
            enhancement & oxidation;

         - Front side first electrode dopant deposition, drive
10   and oxidation;

         - Front side contact opening;

         - Front and back side metal deposition and sintering.

b)   The following steps are the objects of this
     invention:

15   - The back side oxide layer grown during initial
            steps of wafer processing is not removed;

         - The additional photo process is applied to open
            contacts in the oxide layer on the back side. This
            photo process could either precede the front side
20   contact openings or may immediately follow it. The
            mask design should be in accord with the

considerations given above in the description of
the first embodiment of the invention.

Figure 5 presents a cross section of an exemplary
photodiode in accordance with the present invention. The

5   topside of the photodiodes may be in accordance with the
prior art, having a protective oxide layer 6 with a patterned
metal layer 7 thereover making contact with the first
electrode. The back side incorporates the increased
reflectivity over the majority of the back side, yet

10   preserves the desired good electrical contact
characteristics, and can be designed to provide a desired
uniformity of responsivity over the photodiode area.

Thus, the present invention provides a design for
silicon photodiodes and photodiode back side structures that

15   provides high quantum efficiency of the photodiode within the
spectral range close to the bandgap, and provides superior
temporal characteristics. The present invention also
provides related fabrication methods for the photodiodes and
photodiode back side structures. The highly reflective back

20   surface structure for silicon photodiodes also greatly
improves the photodiode temporal characteristics and,
therefore, is useful in construction of fast photodiodes in
near infrared spectral range.